

US007969044B2

(12) **United States Patent**
Armstrong et al.

(10) **Patent No.:** **US 7,969,044 B2**
(45) **Date of Patent:** **Jun. 28, 2011**

(54) **SYSTEM HAVING A VARIABLE FREQUENCY POWER DISTRIBUTION BUS FOR DRIVING A VARIABLE SPEED MOTOR**

(75) Inventors: **Richard Armstrong**, Princeton, MA (US); **Edward Thaxton**, Groton, MA (US)

(73) Assignee: **DRS Power Technology, Inc.**, Fitchburg, MA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 116 days.

(21) Appl. No.: **12/354,146**

(22) Filed: **Jan. 15, 2009**

(65) **Prior Publication Data**

US 2009/0184575 A1 Jul. 23, 2009

Related U.S. Application Data

(60) Provisional application No. 61/021,754, filed on Jan. 17, 2008.

(51) **Int. Cl.**

H02J 3/38 (2006.01)

H02J 9/00 (2006.01)

H02P 9/00 (2006.01)

(52) **U.S. Cl.** **307/86; 307/44; 307/47; 307/68; 307/84; 307/85; 322/44; 322/89**

(58) **Field of Classification Search** **307/84, 307/85, 86, 44, 47, 68; 322/44, 89**
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

1,390,624 A 9/1921 Lammes
1,417,342 A 5/1922 Martin et al.

2,163,140 A	6/1939	Coleman et al.
4,661,714 A	4/1987	Satterthwaite et al.
4,868,406 A	9/1989	Glennon et al.
5,199,912 A	4/1993	Dade et al.
5,684,690 A	11/1997	Levedahl
5,764,502 A	6/1998	Morgan et al.
6,150,731 A	11/2000	Rinaldi et al.
6,175,163 B1	1/2001	Rinaldi et al.
6,188,139 B1	2/2001	Thaxton et al.
6,957,990 B2	10/2005	Lowe
7,121,905 B2	10/2006	Rzadki
7,219,673 B2	5/2007	Lemak
7,692,335 B2 *	4/2010	Michalko 307/84
2006/0108882 A1	5/2006	Michalko

OTHER PUBLICATIONS

International Search Report dated Mar. 27, 2009 corresponding to PCT/US09/31181.

* cited by examiner

Primary Examiner — Jared J Fureman

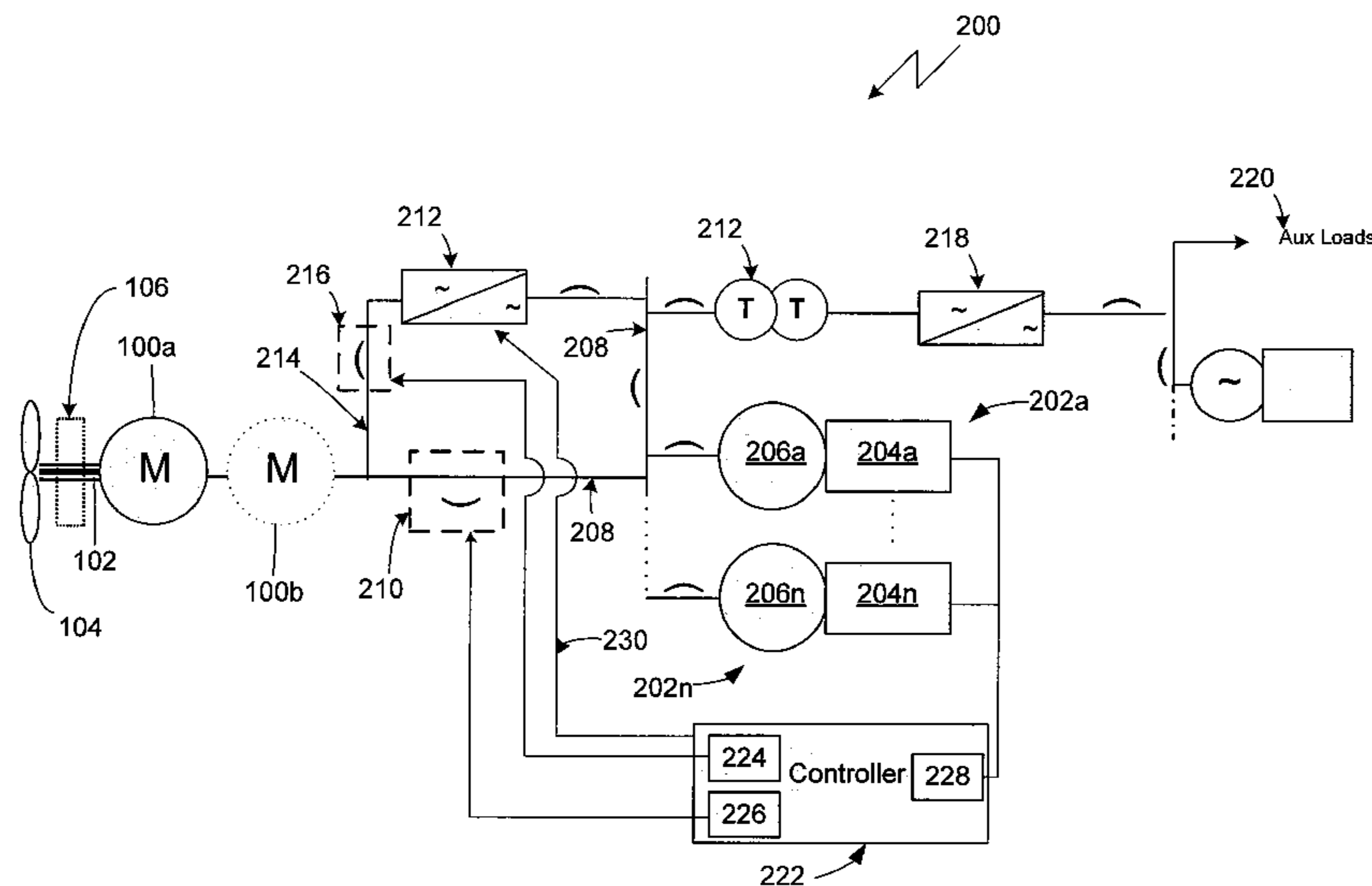
Assistant Examiner — Hal I Kaplan

(74) *Attorney, Agent, or Firm* — SNR Denton US LLP

(57) **ABSTRACT**

A power distribution system is provided for supplying power to a variable speed motor for rotating a shaft. The system comprises a variable speed prime mover adapted to generate an A/C output having a variable frequency corresponding to the speed of the prime mover, a power switch, a power distribution bus connected to the A/C output of the prime mover and connected, via the switch, to the motor such that the motor's speed is varied relative to the frequency of the A/C output, and a variable frequency drive operatively connected to the A/C output of the prime mover via the bus and effective to provide an alternate A/C output to the motor after the motor is disconnected from the bus. The switch is adapted to disconnect the motor from the bus when the prime mover's speed is equal to or within a predetermined range of the prime mover's speed limit.

15 Claims, 2 Drawing Sheets



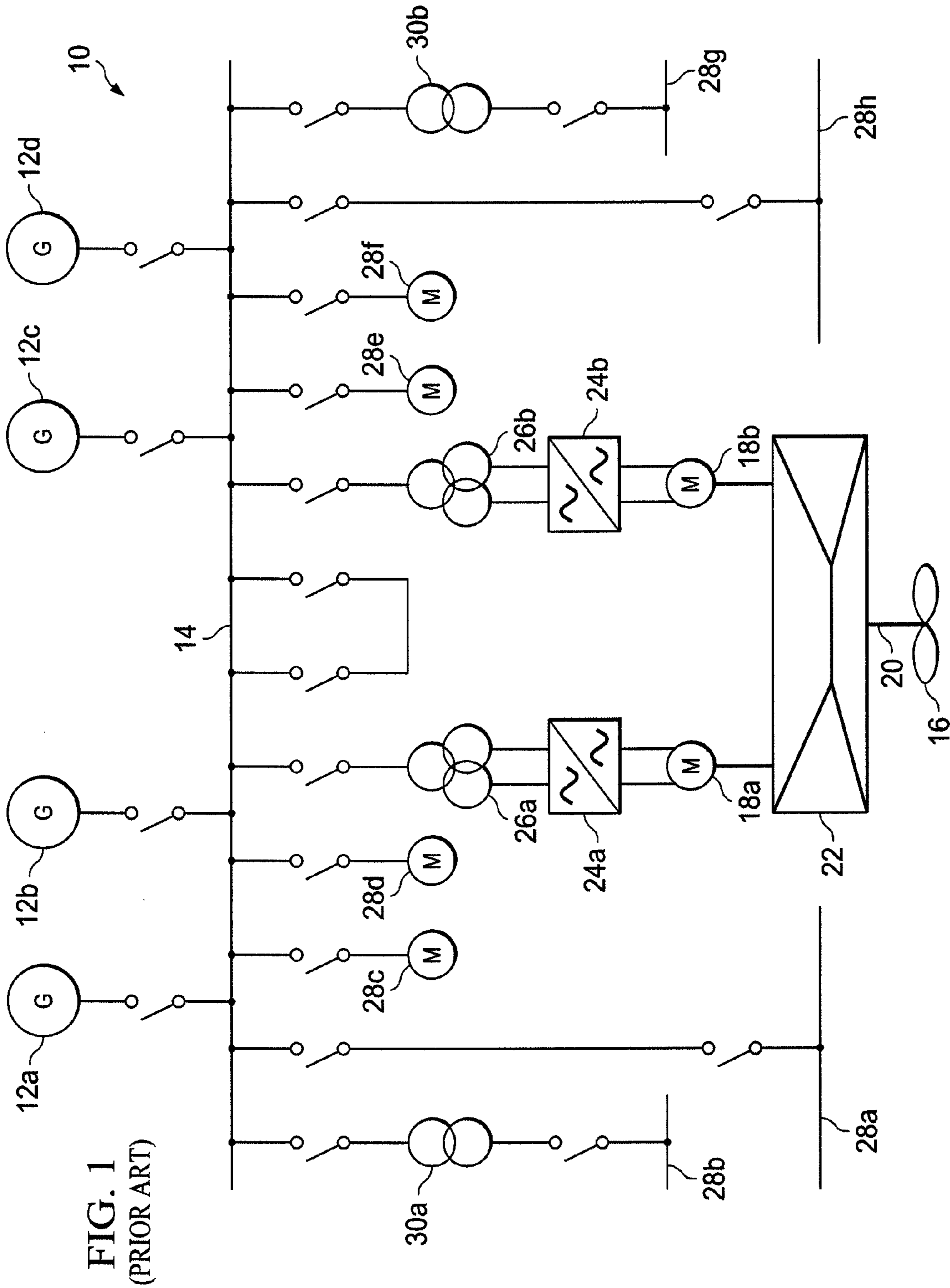


FIG. 1
(PRIOR ART)

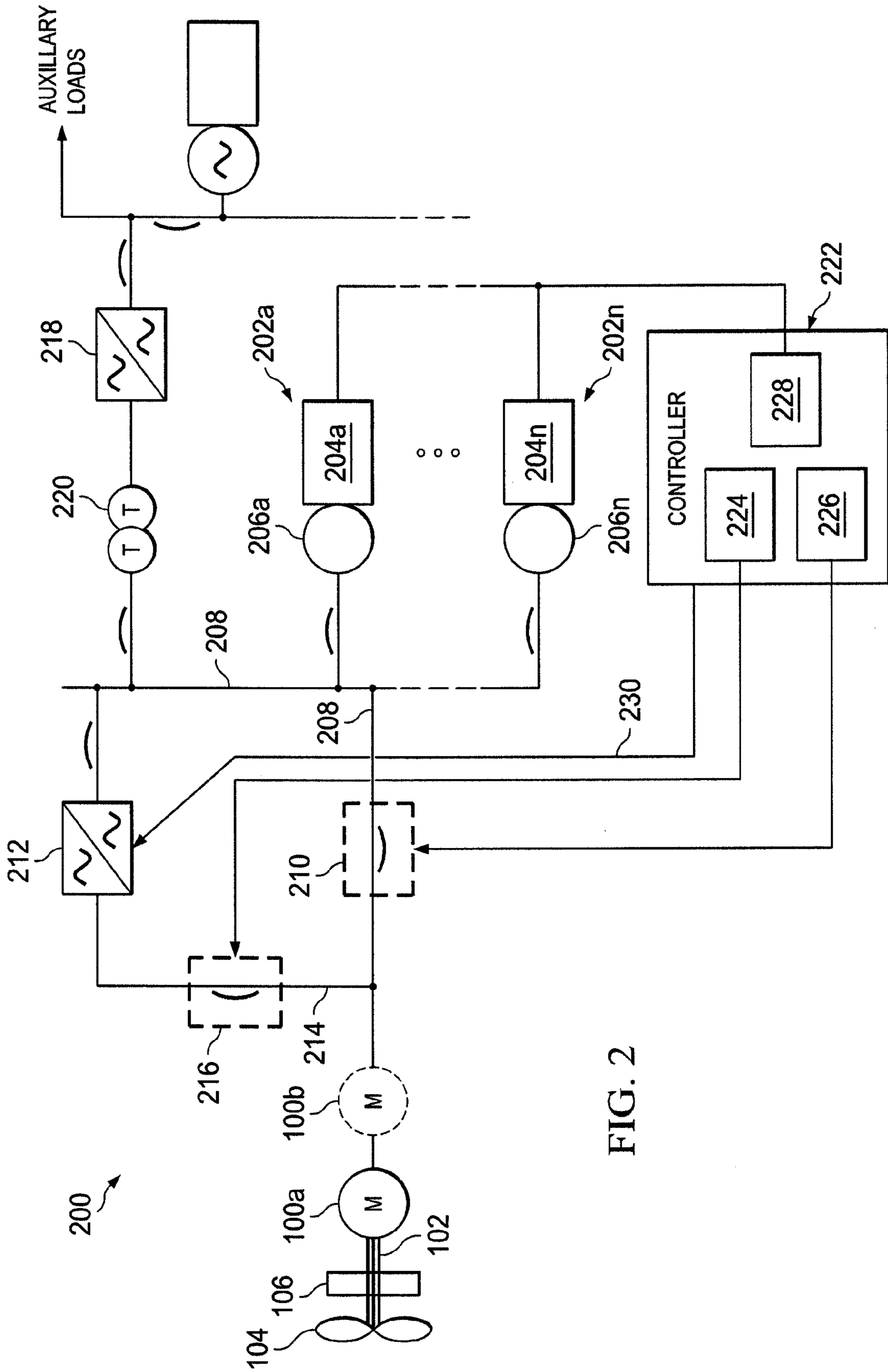


FIG. 2

1

**SYSTEM HAVING A VARIABLE FREQUENCY
POWER DISTRIBUTION BUS FOR DRIVING
A VARIABLE SPEED MOTOR**

CROSS-REFERENCE TO RELATED
APPLICATIONS

This application claims the benefit of the filing date of U.S. Provisional Applications No. 61/021,754, titled "A System Having A Variable Frequency Power Distribution Bus For Driving A Variable Speed Motor," filed on Jan. 17, 2008, which is incorporated herein by reference to the extent permitted by law.

FIELD OF THE INVENTION

The present invention relates to power distribution systems, more particularly, to a system having a variable frequency power distribution bus for driving a variable speed motor.

BACKGROUND OF THE INVENTION

Conventional power distribution systems for ships or other vehicles typically employ one or more prime movers (such as a steam turbine or diesel engine used to drive an electric generator or alternator) to provide a single frequency power supply current on a bus for powering and controlling variable speed motors to operate a propeller in association with supplying auxiliary power to other ship loads (e.g., a single frequency A/C input pump, blower, lamp, or other electrical A/C and D/C loads). In certain conventional power distribution systems for ships or other vehicles, the auxiliary loads and main propulsion loads may be driven by separate prime movers or generators via separate power distribution busses. Thus, in such conventional power distribution systems, the auxiliary loads and main propulsion loads are not electrically connected to each other via the same power distribution bus.

A conventional electrical power distribution system **10** for a ship, as shown in FIG. **1**, typically employs multiple generators **12a-12d** to source a single frequency, single voltage power distribution bus **14**. To operate the ship's propeller **16**, two variable, high speed motors **18a-18b** capable of rotating a rotor shaft **20** within 0-600 RPM are typically coupled to the propeller **16** through a speed reducing gear box **22**. Since the conventional power distribution bus **14** only supplies a single frequency and voltage, two conventional high power (e.g., 1000 kW output or more), variable frequency drives (VFDs) **24a-24b** are required to supply the variable frequency input needed to operate the two high power, variable speed motors **18a-18b** at a range of speeds. Accordingly, as shown in FIG. **1**, VFDs **24a-24b** are commonly coupled between the single frequency, single voltage power distribution bus **14** (usually via a respective transformer **26a-26b**) and the variable, high speed motors **18a-18b**. Other auxiliary loads **28a-28h** (such as a ballast pump or a blower motor) that require only a single frequency and voltage power input (as opposed to the variable frequency and voltage input required by the motors **18a-18b**) are typically coupled either directly to the single frequency, single voltage power distribution bus **14** or via a step down transformer **30a-30b**.

The high power VFDs **24a-24b** required to operate the variable speed motors and, thus, the speed of the propeller, are often expensive and increase the power consumption and overall costs of the conventional power distribution system **10**.

2

Certain older conventional oil tankers, such as the T2-SEA1 tanker built in circa 1940 by the Sun Shipbuilding Company, employed a steam turbine driven alternator to power and control a 2300 volt 3 phase synchronous/induction electric motor that was directly coupled to the tanker's propeller shaft. A separate 75 kw 110 volt dc generator was required to provide a 110-volt dc excitation to the motor's rotor for synchronous mode operation. This motor normally operated in synchronous mode when the motor was started and running at a non-idle speed in step with the turbine driven alternator. However, to start and run up this motor, it was necessary to place the motor in induction mode. This was achieved by short-circuiting the motor's rotor slip rings, which normally carried the 110-volt dc excitation current to the motor's rotor windings. As soon as the motor got up to speed, which was observed by ammeters falling back, the short circuit was removed and the 110-volt dc excitation current applied to the motor's rotor slip rings to transition to synchronous mode. A person at the motor controls carried out this operation manually. Auxiliary power for other loads on this conventional tanker was provided by a separate steam turbine driven 400 kw, 440 volt 3 phase alternator. Thus, this older conventional oil tanker required separate power distribution busses for the main propeller motor and other ship loads.

Therefore, there is a need for a common power distribution bus that overcomes the problems noted above and others previously experienced for supplying power and controlling a variable speed motor to operate a propeller shaft or other variable speed load while avoiding the inefficiencies and costs of using variable frequency converters between the prime movers and the loads.

SUMMARY OF THE INVENTION

Systems and articles of manufacture consistent with the present invention provide a power distribution system for a ship or other vehicle or platform having a variable speed motor for operating a shaft, such as a propeller. The power distribution system comprises a variable speed prime mover adapted to generate an A/C output having a variable frequency corresponding to the speed of the prime mover. The speed of the prime mover is equal to or greater than a predetermined speed limit (e.g., idling speed). The power distribution system also includes a power switch and a power distribution bus connected to the A/C output of the prime mover and connected, via the power switch, to the variable speed motor such that the speed of the motor is varied relative to the frequency of the A/C output. The power switch is adapted to disconnect the variable speed motor from the bus when the speed of the prime mover is equal to or within a predetermined range of the predetermined speed limit. The power distribution system further includes a variable frequency drive operatively connected to the A/C output of the prime mover via the power distribution bus and operatively configured to provide an alternate A/C output to the motor after the variable speed motor is disconnected from the power distribution bus. The variable frequency drive may be connected to the motor in parallel with the prime mover via the power distribution bus.

In another embodiment consistent with the present invention, another power distribution system for supplying power to a variable speed motor for rotating a shaft is provided. The power distribution system comprises a plurality of variable speed prime movers and a prime mover controller. Each of the prime movers is operatively configured to generate an A/C output having a variable frequency corresponding to the speed of the respective prime mover. The speed of each of the

prime movers is equal to or greater than a predetermined speed limit. The prime mover controller is operatively connected to each prime mover and operatively configured to vary the speed of each prime mover in unison. The power distribution system further includes a power switch operatively connected to and controlled by the prime mover controller, and a power distribution bus. The power distribution bus is connected to the A/C output of each of the prime movers and connected, via the power switch, to the variable speed motor such that the speed of the motor is selectively varied relative to the frequency of the combined A/C outputs of the prime movers. The prime mover controller is operatively configured to actuate the power switch to disconnect the variable speed motor from the bus when the speed of the prime mover is equal to or within a first predetermined range of the predetermined speed limit. The power distribution system also includes a variable frequency drive operatively connected to the combined A/C outputs of the prime movers via the power distribution bus and operatively configured to provide an alternate A/C output to the motor after the variable speed motor is disconnected from the power distribution bus.

Other systems, methods, features, and advantages of the present invention will be or will become apparent to one with skill in the art upon examination of the following figures and detailed description. It is intended that all such additional systems, methods, features, and advantages be included within this description, be within the scope of the invention, and be protected by the accompanying claims.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings, which are incorporated in and constitute a part of this specification, illustrate an implementation of the present invention and, together with the description, serve to explain the advantages and principles of the invention. In the drawings:

FIG. 1 is a block diagram of a conventional power distribution system for a ship, in which multiple prime movers provide a single frequency power supply current on a bus for powering and controlling (via respective VFD units) variable speed motors to operate a propeller in association with supplying auxiliary power to other ship loads; and

FIG. 2 is a block diagram depicting an exemplary power distribution system for a ship consistent with the present invention.

DETAILED DESCRIPTION OF THE INVENTION

Reference will now be made in detail to an implementation in accordance with methods, systems, and products consistent with the present invention as illustrated in the accompanying drawings.

FIG. 2 is a block diagram depicting an exemplary power distribution system 200 for a ship consistent with the present invention. The power distribution system 200 supplies power to and controls the speed of one or more variable speed motors 100a and 100b for driving or rotating a shaft 102 and operating a primary load, such as a propeller 104, that is coupled to the shaft 102. A conventional gear box 106 may be employed to couple the propeller 104 to the shaft 102 driven by the motor 100a and/or 100b. Each motor 100a and 100b may be a synchronous motor, an induction motor, a permanent magnet motor, or any other type of variable speed, electric motor that generates a mechanical rotary or linear force for rotating the shaft 102 at a speed corresponding to an A/C input to the motor 100a and 100b.

Note the second motor 100b is shown in dashed lines in FIG. 2 to reflect that the second motor 100b is optional and not required to implement the power distribution system 200 in accordance with the present invention. However, should additional torque be required to rotate the shaft 102 to effectively operate the propeller 104, the power distribution system 200 as described herein enables a second motor 100b to be coupled to the shaft 102 in series with the first motor 100a.

Although the power distribution system 200 is shown and described herein for a ship, one of ordinary skill in the art will appreciate (upon review of the present application) that the power distribution system 200 may be suitable for providing power to a variable speed motor used in other applications.

As shown in FIG. 2, the power distribution system 200 comprises one or more variable speed prime movers 202a-202n adapted to generate an A/C output having a variable frequency corresponding to the speed of the respective prime mover 202a-202n. Each prime mover 202a-202n may comprise a steam turbine, diesel engine, or other engine 204a-204n and an electric generator 206a-206n that is driven by the engine to generate the variable frequency A/C output of the respective prime mover 202a-202n. The speed of each prime mover 202a-202n is equal to or greater than a predetermined speed limit associated with the prime mover 202a-202n. When the prime mover 202a is operating at its speed limit or lower end of the prime mover's operating range, the generator 206a generates an A/C output at a frequency (e.g., 20 Hz) corresponding to the speed limit of the prime mover 202a.

As described in further detail below, the power distribution system 200 enables the speed of the motor 100a (or motors 100a-100n) to be varied relative to the speed of the prime movers 202a-202n (and, thus, the frequency of the A/C output of prime movers 202a-202n), when the speed of the prime movers 202a-202n is equal to or greater than the predetermined speed limit of the prime movers 202a-202n. When the prime movers 202a-202n are operated at the predetermined speed limit, the power distribution system 200 switches A/C input to the motor 100a directly from the prime movers 202a-202n to a low power variable frequency drive (e.g., 212 in FIG. 2) to provide idle speed control for the motor 100a.

As shown in FIG. 2, the power distribution system 200 includes a power distribution bus 208 that is connected to the A/C output of each prime mover 202a-202n and connected, via a power switch 210, to the variable speed motor 100a such that the speed of the motor 100a (and/or 100b) is varied relative to the frequency of the A/C output of a respective prime mover (e.g., 202a) or the combined A/C output of the prime movers 202a-202n. The power switch 210 may be a circuit breaker switch or other switch that may be selectively actuated to disconnect the motor 100a (or motors 100a and 100b) from the power distribution bus 208. The power switch 210 is adapted to disconnect the variable speed motor or motors 100a-100n from the bus 208 when the speed of the prime mover is equal to or within a predetermined range (such as 0 to 2 rpms) of the predetermined speed limit.

To control each motor 100a and 100b after the prime movers 202a-202n reach their respective predetermined speed limit, the power distribution system 200 includes a variable frequency drive 212 that is operatively connected to the A/C output of the prime movers 202a-202n via the power distribution bus 208 and operatively configured to provide an alternate A/C output to the motor (via a separate bus 214) after the variable speed motor 100a is (or motors 100a and 100b are) disconnected from the power distribution bus 208. Accordingly, the variable frequency drive 212 is operatively configured to provide the alternate A/C output to the motor 100a when the speed of the prime mover 202a-202n is less than the

5

predetermined speed limit at which time the power switch **210** is actuated to disconnect the motor **100a** from the bus **208**. The variable frequency drive **212** may be a standard motor drive that may be configured or selectively controlled to provide a variable A/C output within a predetermined range of frequencies (e.g., 0 to 60 Hz) based on a substantially fixed A/C input (e.g., 60 Hz+/-2 Hz).

The power distribution system **200** may also include a second power switch **216** adapted to connect the alternate A/C output of the variable frequency drive **212** to the motor **100a** when or after the speed of the prime mover **202a-202n** is less than the predetermined speed limit of the prime mover **202a-202n**. The power switch **216** may be a circuit breaker switch or other switch that may be selectively actuated to disconnect the A/C output of the frequency drive **212** from the motor **100a** or the separate bus **214**. In one implementation, the second power switch **216** is incorporated into the variable frequency drive **212**.

The power distribution system **200** may further comprise a second variable frequency drive **218** operatively connected to the A/C output of the prime mover **202a-202n** via the power distribution bus **208** and operatively configured to generate a single frequency A/C output (e.g., 60 Hz) based on the variable frequency A/C output of the prime mover **202a-202n**. The A/C output of the second variable frequency drive **218** may be used to provide power to auxiliary loads (not shown in the figures). As shown in FIG. 2, a transformer **220** may be disposed between the power distribution bus **208** and the second variable frequency drive **218** to step down the A/C voltage on the bus **208** to the drive **218**.

The power distribution system **200** may also include a prime mover controller **222** operatively connected to each prime mover **202a-202n** and operatively configured to selectively vary the speed of each prime mover **202a-202n** in unison. In one implementation, the controller **222** may include a user adjustable mechanical link (not shown in Figures) connected to each prime mover **202a-202n** to adjust the pole arrangement of the respective prime mover **202a-202n** to correspondingly adjust the speed and A/C frequency output of the prime mover **202a-202n**.

The controller **222** is adapted to determine or sense when the prime movers **202a-202n** each have reached or is within a predetermined range (e.g., 0 to 2 rpm) of their respective speed limit and, in response, actuate the first power switch **210** to disconnect the motor **100a** from the power distribution bus **208** and allow the variable frequency drive **212** to provide the alternate A/C output to the motor **100a**. In one implementation, when or after the first power switch **210** is actuated to remove the motor **100a** from the power distribution bus **208**, the controller **222** is operatively configured to actuate the second power switch **216** to connect the A/C output of the variable frequency drive **212** to the A/C input of the motor **100a**. When the speed of each of the prime movers **202a-202n** is adjusted via the controller **222** to be greater than the predetermined speed limit of the respective prime movers **202a-202n**, the controller **222** de-actuates the second power switch **216** to disconnect the A/C output of the variable frequency drive **212** to the A/C input of the motor **100a** and re-actuates the first power switch **210** to reconnect the A/C output of the variable frequency drive **212** to the power distribution bus **208**.

The controller **222** may include D/A converters **224** and **226** for providing the actuation/de-actuation signals to the power switches **210** and **216**. The controller **222** may also include may comprise an I/O unit **228** that has a plurality of A/D converters for providing a respective speed control signal to each prime mover **202a-202n** in accordance with the

6

present invention. The controller **222** may further provide one or more control signals **230** to the variable frequency drive **212** to control the low or idle speeds (e.g., 0 to 10 rpms) of the motor **100a** and **100n** in accordance with the present invention. The controller **222** may be implemented in hardware alone (such as ASIC device) or in hardware and software, including a microprocessor and a memory holding a program run by the microprocessor to control the prime movers **202a-202n** and the power switches **210** and **216** as described herein.

Accordingly, the power distribution system **200** enables the speed of the prime mover **202a-202n** to be selectively varied to correspondingly vary the frequency on the power distribution bus **208** and, in turn, directly control the speed of the variable speed motor **100a** while simultaneously providing power (via the second variable frequency drive **218**) to auxiliary loads. In addition, when the speed of each prime mover **202a-202n** is equal to or within a first predetermined range of the prime mover's predetermined speed limit, the power distribution system **200** disconnects the variable speed motor **100a** from the power distribution bus **208** and enables a variable frequency drive **212** that remains connected to the power distribution bus **208** to provide an alternate A/C output to the motor **100a** for controlling the motor **100a** at low or idle speeds (e.g., 0 to 10 rpms).

The power distribution system **200** with a variable frequency, power distribution bus **208** implemented in accordance with the present invention eliminates the need for the combination of transformers and variable frequency drives required to drive high power, variable speed motors in the conventional power distribution systems, saving cost and improving energy efficiency for the system **200**.

While various embodiments of the present invention have been described, it will be apparent to those of skill in the art that many more embodiments and implementations are possible that are within the scope of this invention. Accordingly, the present invention is not to be restricted except in light of the attached claims and their equivalents.

What is claimed is:

1. A power distribution system for supplying power to a variable speed motor for rotating a shaft, comprising:
 - a variable speed prime mover adapted to generate an A/C output having a variable frequency corresponding to the speed of the prime mover, the speed of the prime mover being equal to or greater than a predetermined speed limit;
 - a power switch;
 - a power distribution bus connected to the A/C output of the prime mover and connected, via the power switch, to the variable speed motor such that the speed of the motor is varied relative to the frequency of the A/C output, the power switch being adapted to disconnect the variable speed motor from the bus when the speed of the prime mover being used to drive the variable speed motor is equal to or within a predetermined range of the predetermined speed limit; and
 - a variable frequency drive operatively connected to the A/C output of the prime mover via the power distribution bus and operatively configured to provide an alternate A/C output to the motor after the variable speed motor is disconnected from the power distribution bus.
2. The power distribution system of claim 1, wherein the variable frequency drive is operatively configured to provide the alternate A/C output to the motor when the speed of the prime mover is less than the predetermined speed limit.
3. The power distribution system of claim 1, further comprising a second power switch adapted to connect the alter-

7

nate A/C output of the variable frequency drive to the motor when the speed of the prime mover is less than the predetermined speed limit.

4. The power distribution system of claim 1, further comprising a second variable frequency drive operatively connected to the A/C output of the prime mover via the power distribution bus and operatively configured to generate a single frequency A/C output based on the variable frequency A/C output of the prime mover.

5. A power distribution system for supplying power to a variable speed motor for rotating a shaft, comprising:

a plurality of variable speed prime movers, each of the prime movers being operatively configured to generate an A/C output having a variable frequency corresponding to the speed of the respective prime mover, the speed of each of the prime movers being equal to or greater than a predetermined speed limit,

a prime mover controller operatively connected to each prime mover and operatively configured to vary the speed of each prime mover in unison;

a power switch operatively connected to and controlled by the prime mover controller;

a power distribution bus connected to the A/C output of each of the prime movers and connected, via the power switch, to the variable speed motor such that the speed of the motor is selectively varied relative to the frequency of the combined A/C outputs of the prime movers, the prime mover controller being operatively configured to actuate the power switch to disconnect the variable speed motor from the bus when the speed of a prime mover being used to drive the variable speed motor is equal to or within a first predetermined range of the predetermined speed limit; and

a variable frequency drive operatively connected to the combined A/C outputs of the prime movers via the power distribution bus and operatively configured to provide an alternate A/C output to the motor after the variable speed motor is disconnected from the power distribution bus.

6. The power distribution system of claim 1, further comprising:

a second power switch configured in series with the variable frequency drive; and

wherein the variable frequency drive and second power switch are in parallel with the power switch.

8

7. The power distribution system of claim 6, further comprising a controller in communication with the power switch and the second power switch, and configured to cause the power switch to disconnect the variable speed motor from the bus and provide the alternate A/C output to the motor after the variable speed motor is disconnected from the power distribution bus.

8. The power distribution system according to claim 1, further comprising a second variable speed motor connected, via the power switch, to the power distribution bus.

9. The power distribution system according to claim 1, wherein the second variable speed motor is connected in series with the variable speed motor.

10. The power distribution system according to claim 1, further comprising:

a transformer connected to the power distribution bus; and a second variable frequency drive connected to the transformer, the second variable frequency drive configured to power auxiliary loads.

11. The power distribution system of claim 5, further comprising:

a second power switch configured in series with the variable frequency drive; and

wherein the variable frequency drive and second power switch are in parallel with the power switch.

12. The power distribution system of claim 11, further comprising a controller in communication with the power switch and the second power switch, and configured to cause the power switch to disconnect the variable speed motor from the bus and provide the alternate A/C output to the motor after the variable speed motor is disconnected from the power distribution bus.

13. The power distribution system according to claim 5, further comprising a second variable speed motor connected, via the power switch, to the power distribution bus.

14. The power distribution system according to claim 13, wherein the second variable speed motor is connected in series with the variable speed motor.

15. The power distribution system according to claim 5, further comprising:

a transformer connected to the power distribution bus; and a second variable frequency drive connected to the transformer, the second variable frequency drive configured to power auxiliary loads.

* * * * *